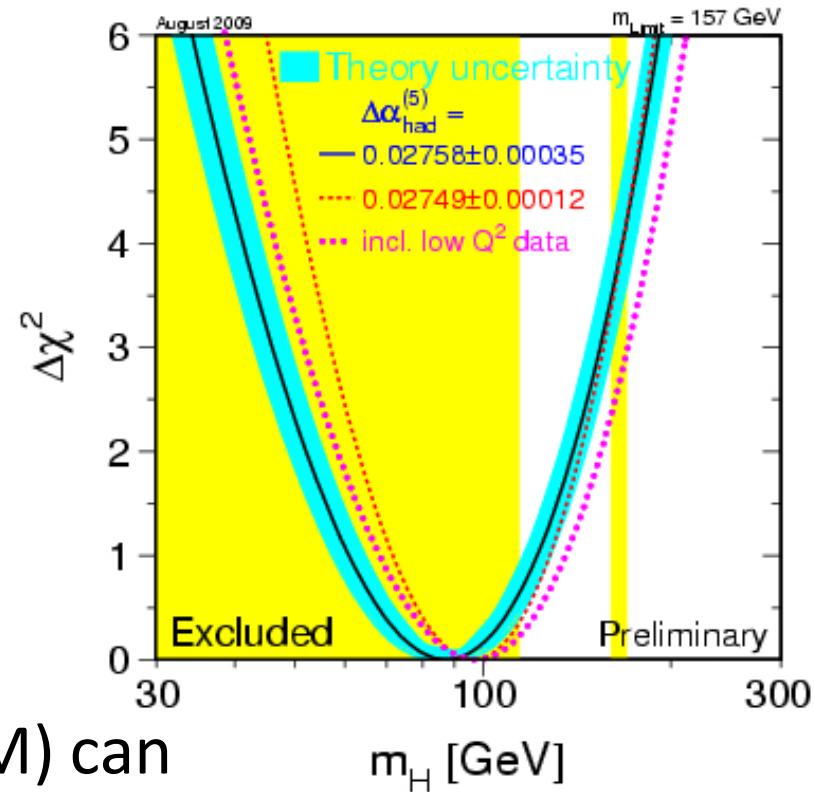


Searches for Higgs Boson at the Tevatron

Alexei Safonov
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for CDF and D0 Collaborations

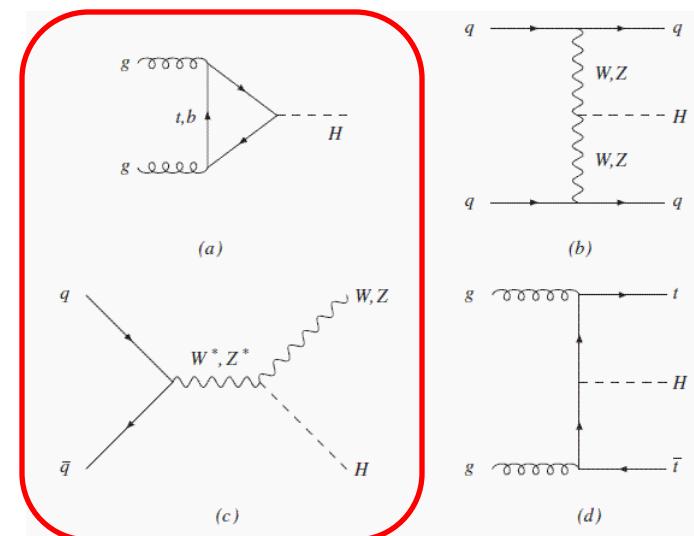
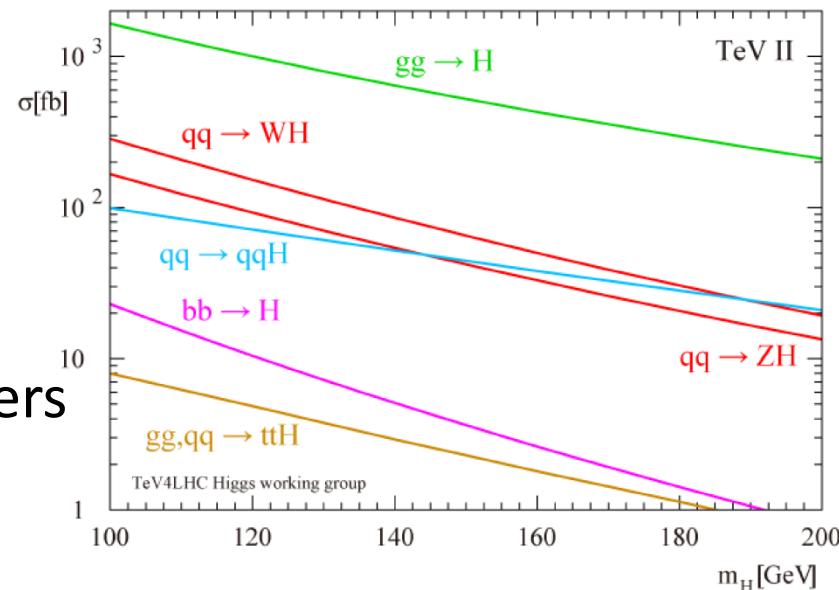
Higgs Today

- At least one SM-like Higgs is required in most models
 - Use SM Higgs for benchmarking, but keep in mind that it can be something more complex
- Direct exclusions:
 - LEP: $m > 114$ GeV
- Indirect:
 - LEP, Tevatron (W/top mass)
 - 95% C.L. $m < 158$ GeV
- Non-SM scenarios (e.g. NMSSM) can weaken both direct and indirect limits



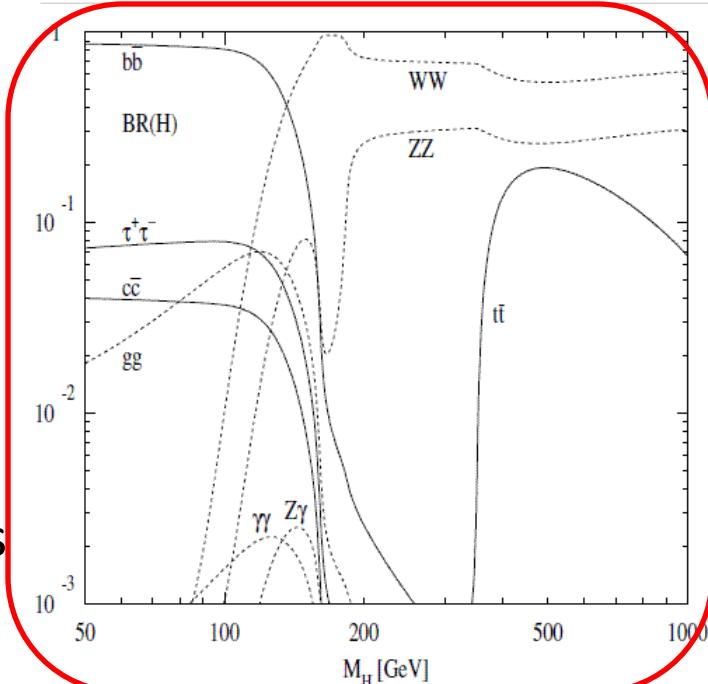
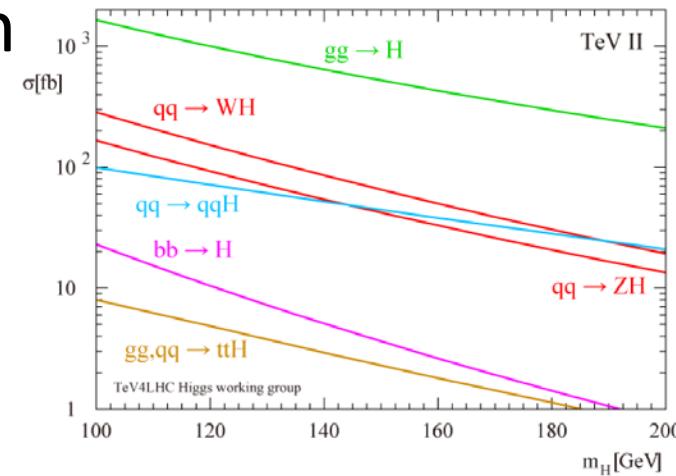
Higgs Production at the Tevatron

- Dominated by gluon fusion
 - But large decay modes often come with large backgrounds
- Associated Production
 - While smaller cross section, offers cleaner final states
- Vector Boson Fusion (VBF)
 - Even smaller cross-section, but can help increase the overall sensitivity
- Have to be inventive and use all accessible modes and many decay channels
 - Improving analysis techniques



Higgs Search Strategies

- Sensitivity strongly depends on backgrounds for a specific decay channel:
- “High mass” $m > \sim 135$ GeV:
 - WW (and ZZ) decay modes
 - Clean final states with leptons, any production mode will do
- “Low mass” $m < \sim 135$ GeV:
 - Associated production:
 - Rely on leptons/neutrinos to reduce background, go after all decay modes (but bb dominates)
 - Gluon fusion:
 - $H \rightarrow bb$ dominated by backgrounds
 - $H \rightarrow \tau\tau$: ok but small BR

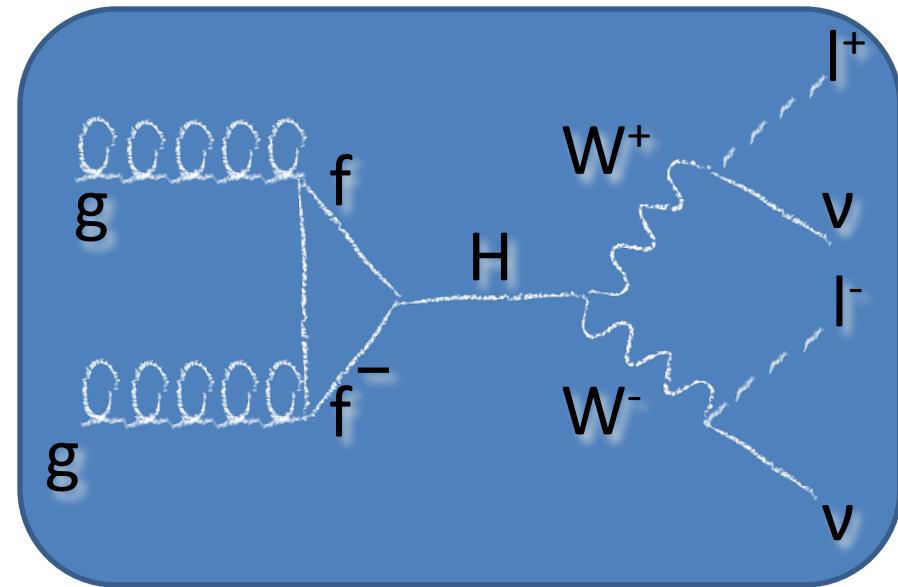


Higgs Searches at the Tevatron

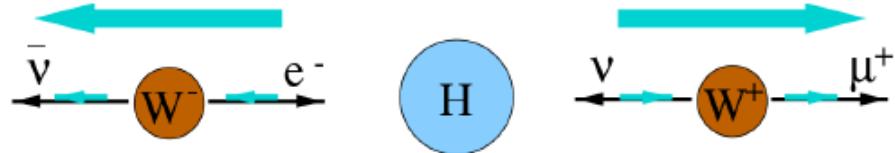
HIGH MASS HIGGS

High Mass Searches

- WW is the best channel
 - Large BR, can use all production modes
- Both experiments rely on advanced techniques and categorizations
 - Neural Net (NN), Matrix Element (ME), Decision Trees (DT)
- Backgrounds:
 - DY, diboson, W+jets
- Selections:
 - 2 OS leptons, MET
 - Leptons+jets
 - LS leptons (WH \rightarrow WWW)

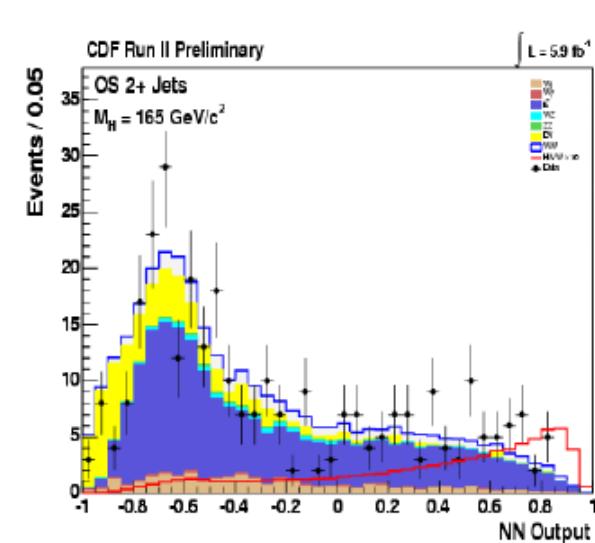
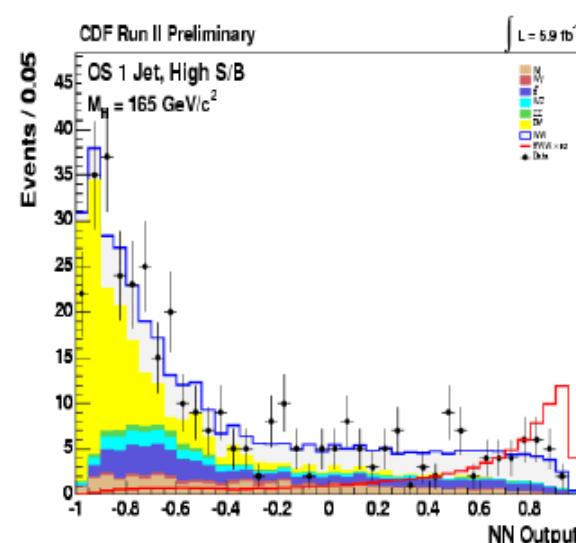
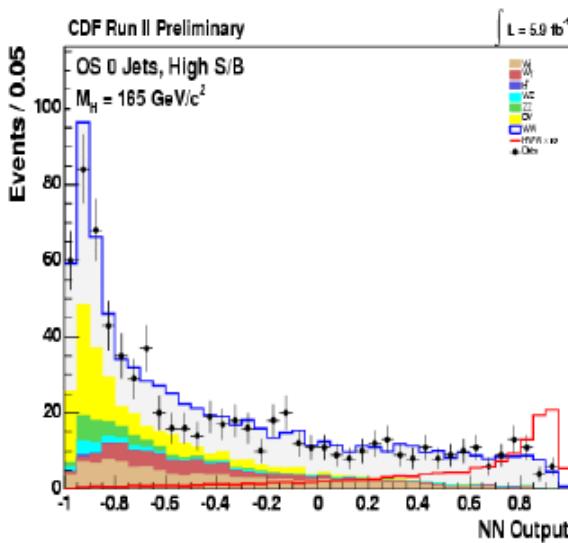


- Helicity conservation:
 - Leptons tend to go in the same directions



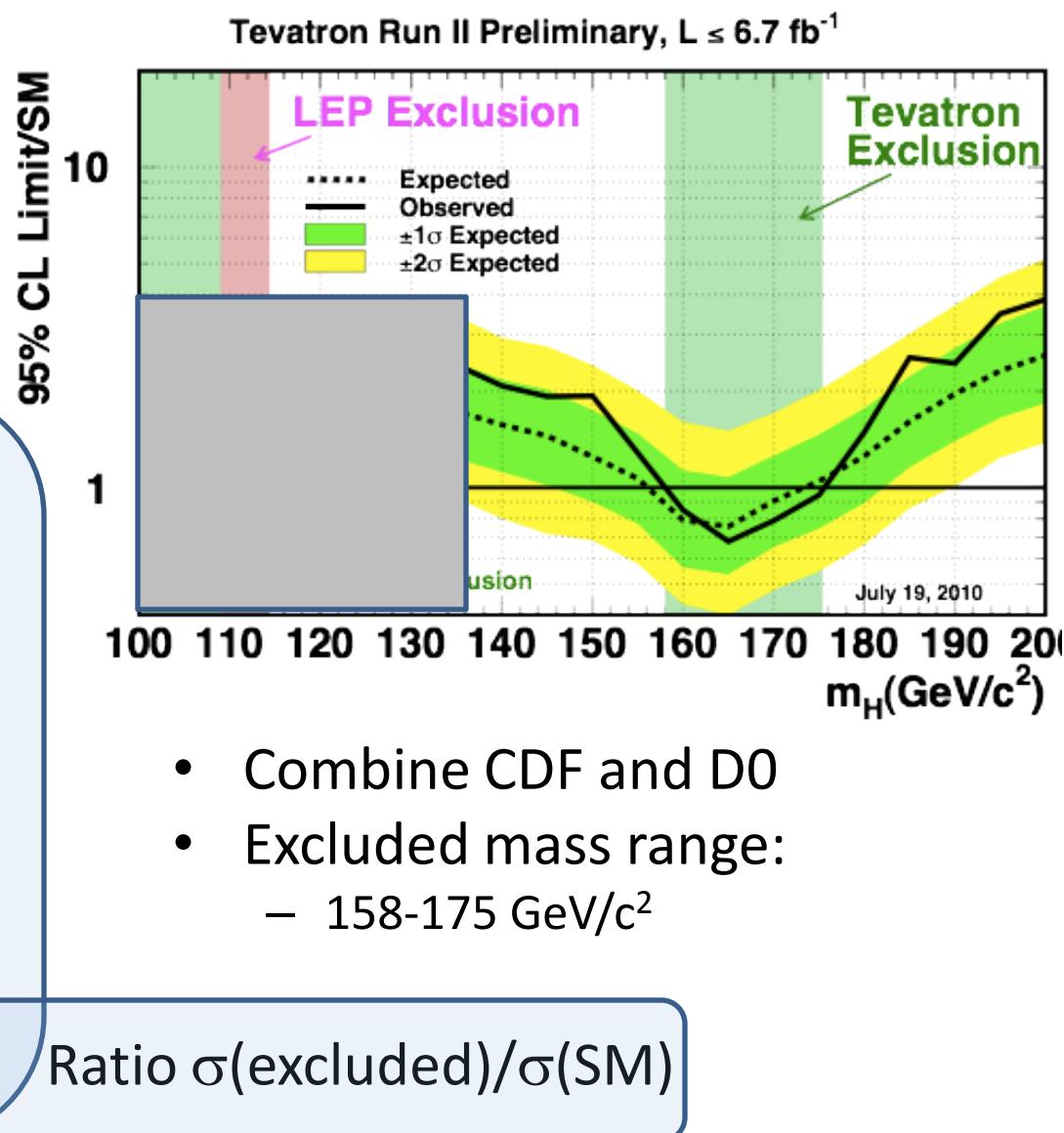
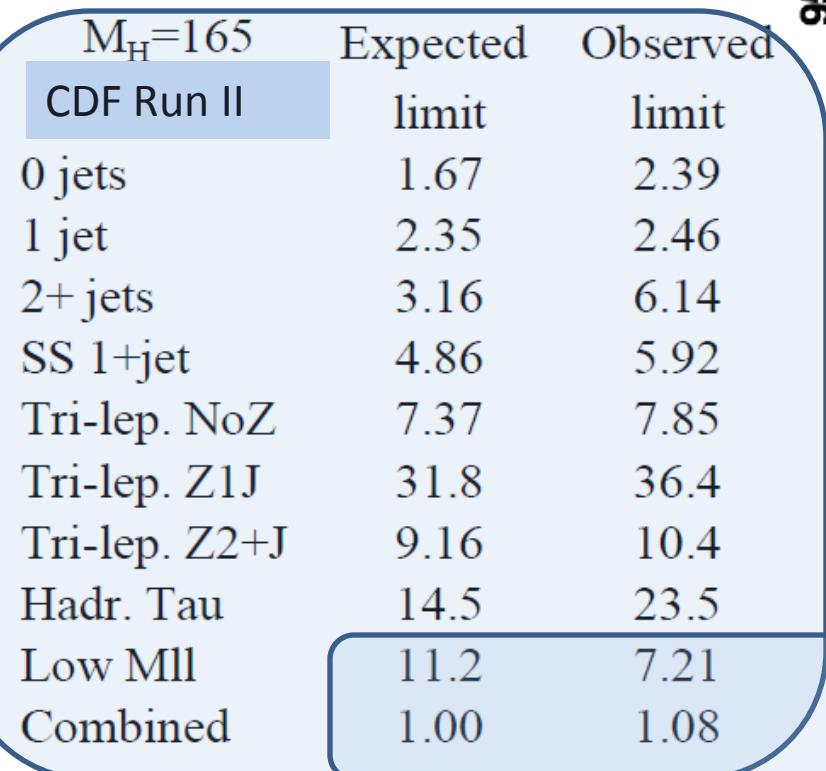
Signal Extraction

- Categorize according to $N_{jet}=0, 1, 2$ in $l\bar{l}+N_{jets}$
 - Adds VBF and associated production with $H \rightarrow WW$
- CDF uses NNs, DO - BDTs
 - Trained on each category separately
 - Inputs: event topology (lepton kinematics, lepton and MET, jets and MET) and quality of leptons



High Mass: Results

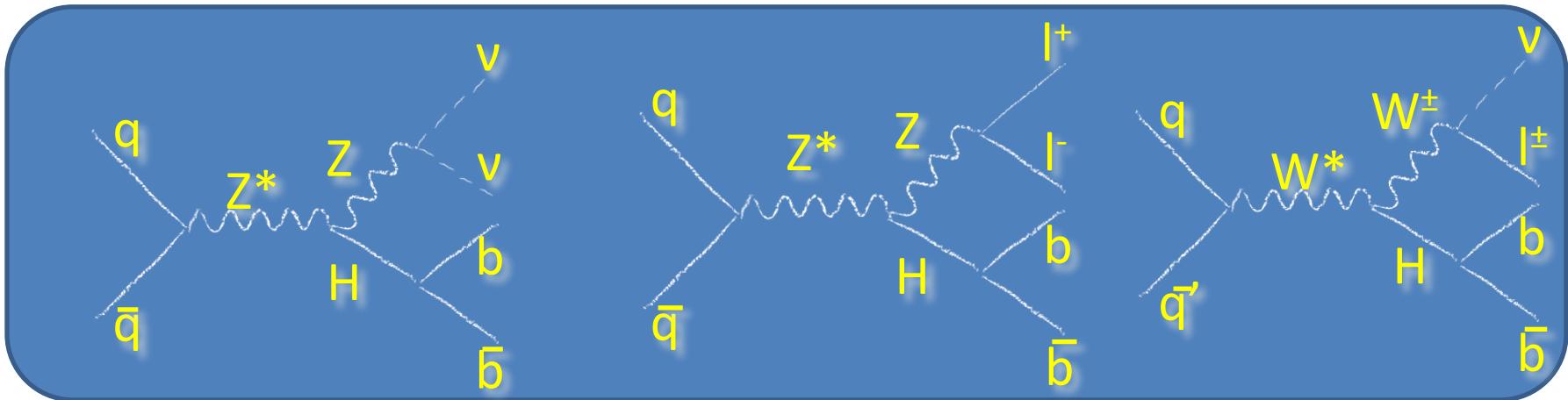
- Combine together multiple analysis channels
 - CDF example shows importance of different contributions



Higgs Searches at the Tevatron

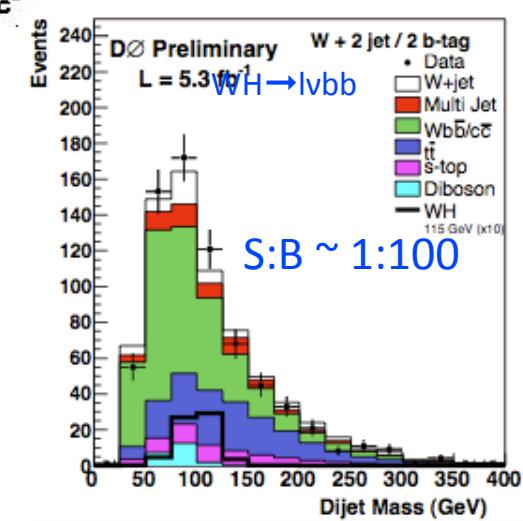
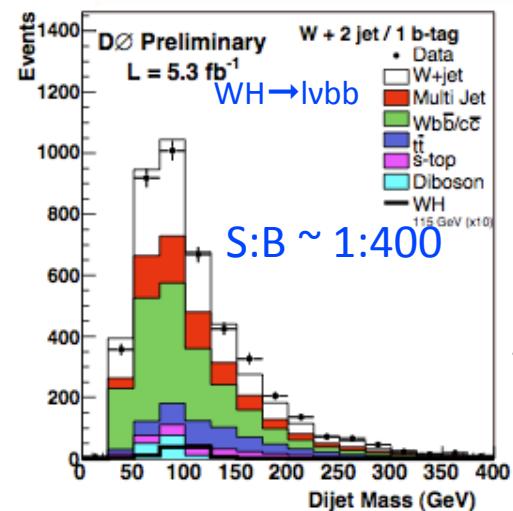
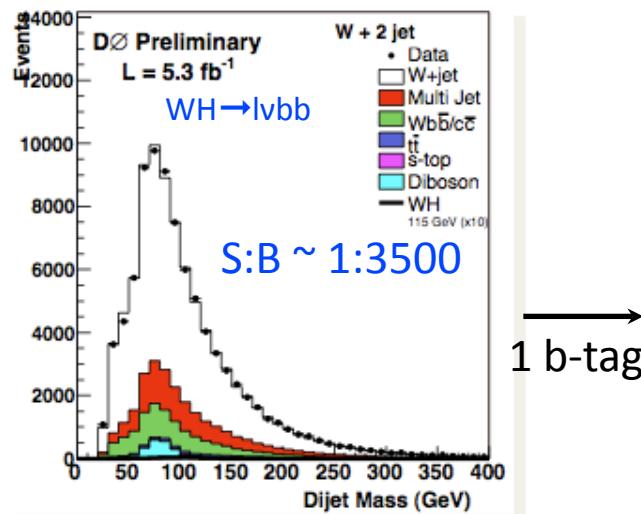
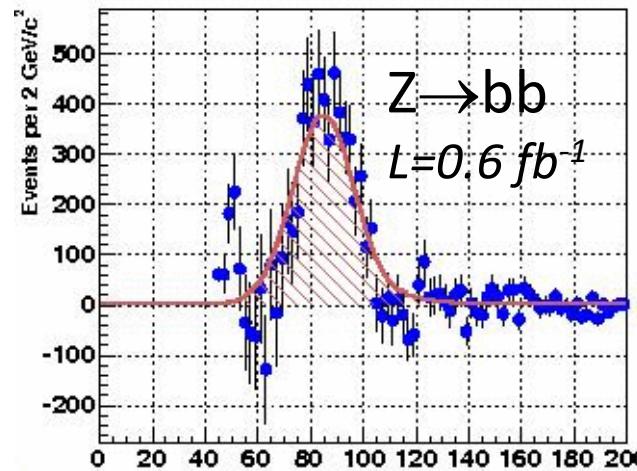
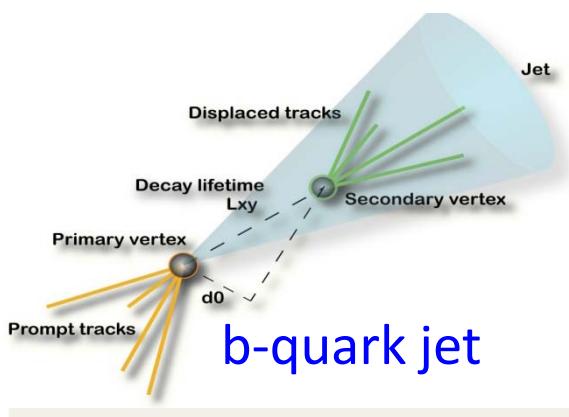
LOW MASS HIGGS

Associated Production Channels



- While smaller cross-section, final states are much cleaner
- Main ingredients:
 - Leptons or MET allow large reduction in backgrounds to go after dominant $b\bar{b}$ decay channel
 - b -tagging dramatically reduces $W/Z + \text{light jet}$ and QCD backgrounds
- Analyses look for a bump in the dijet spectrum
 - Good understanding of $b\bar{b}$ mass resolution is critical

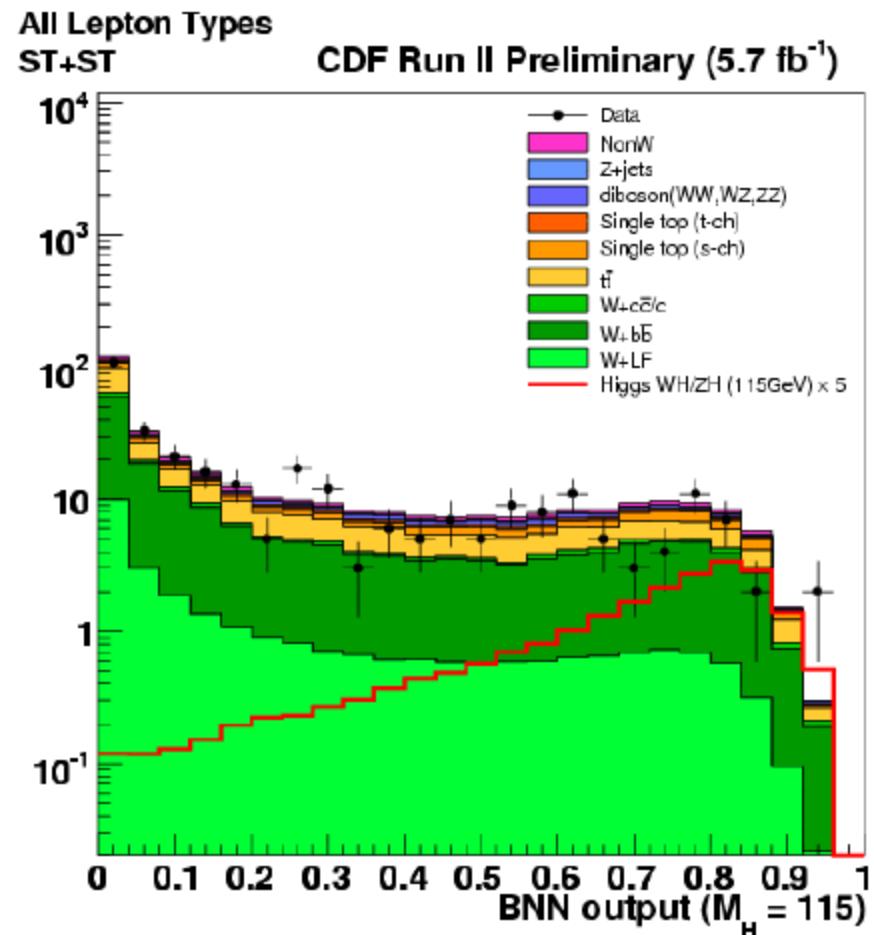
Backgrounds and Resolution



- After 1 or 2 b-tags
Signal region with enhanced signal / background

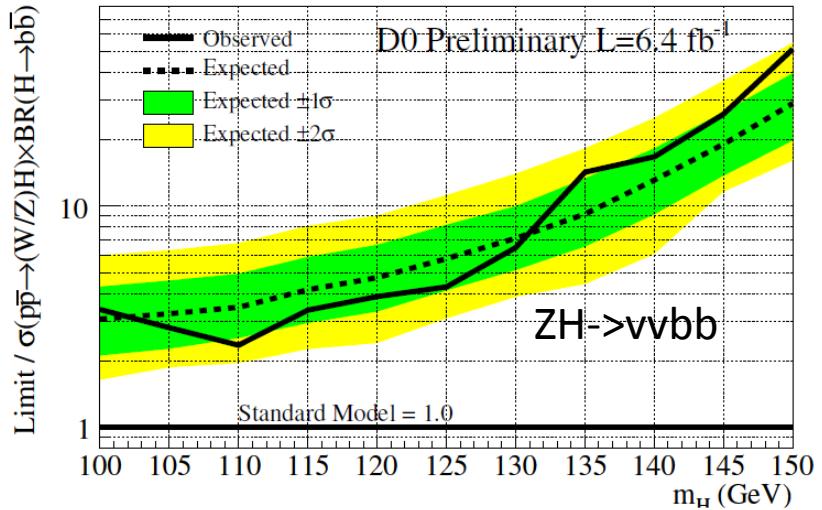
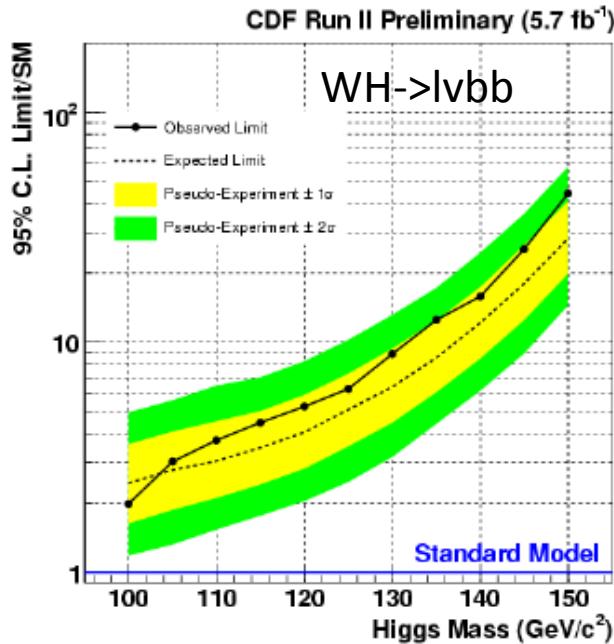
Multivariate Techniques

- Both experiments rely on advanced techniques
 - NN, ME, DT
 - Validated in other analyses, requires excellent understanding of the detectors
 - Extensive categorization to improve sensitivity
 - E.g. 4 b-taggers (displaced vertex, track impact parameter, NN)
 - Multiple lepton categories including loose ones to increase acceptance



- Bayesian NN output in WH->lvbb analysis

Low Mass Limits

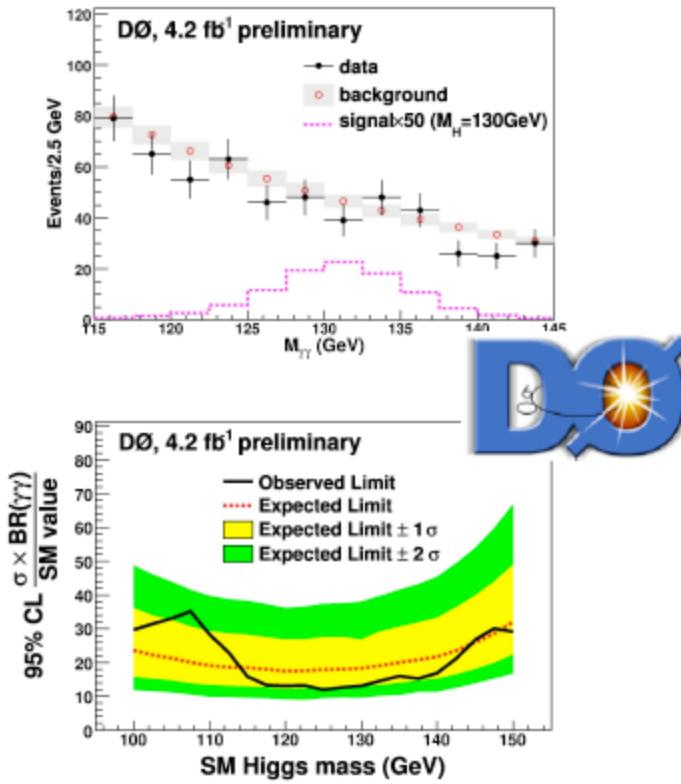
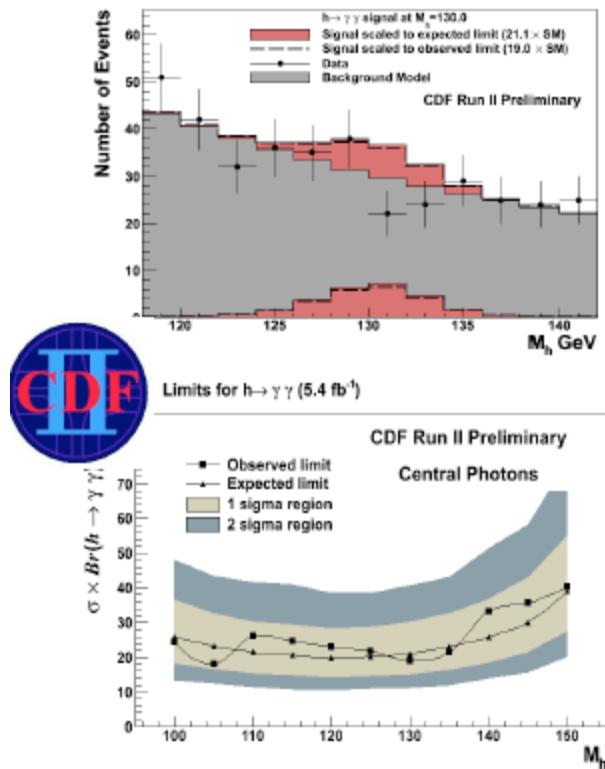


Channel	Expected $\sigma(\text{excl})/\sigma(\text{SM})$ for $m=115 \text{ GeV}$
WH → lνbb	<3.5
VH in MET+bb	<4.0
ZH → llbb	<5.5
VH in qqbb	<18
$\gamma\gamma$	<21
$2\tau+2j$	<23
Combined	<1.9

- Data consistent with expectation
- Sensitivity ranking list of channels
 - Use CDF as an example

“New” Low Mass Channel: $H \rightarrow \gamma\gamma$

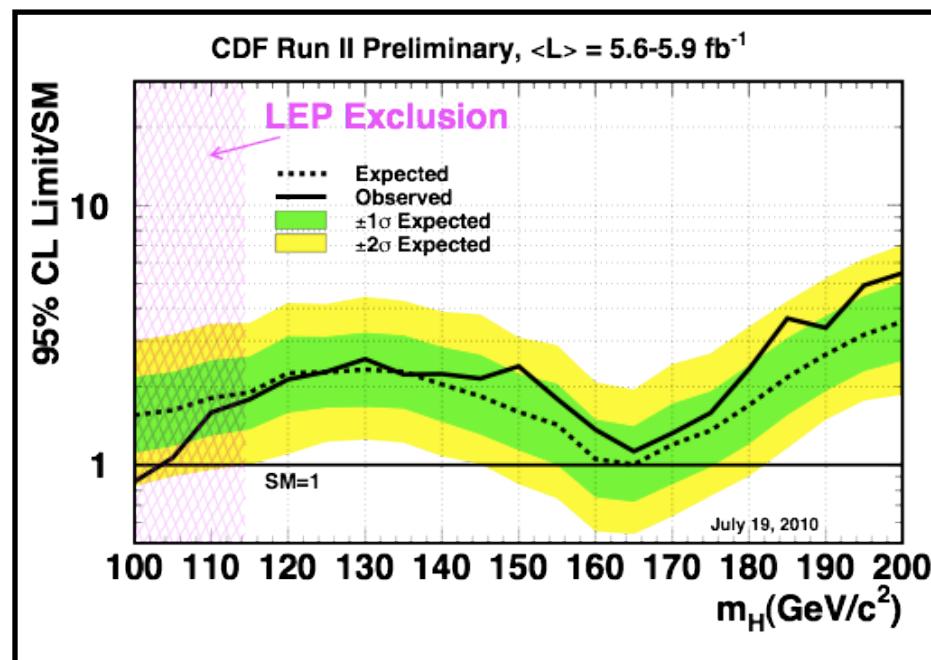
- “Discovery” mode at the LHC
 - Small BR $\sim 0.2\%$, but a narrow bump
 - Sensitivity is a strong function of EM calorimeter resolution



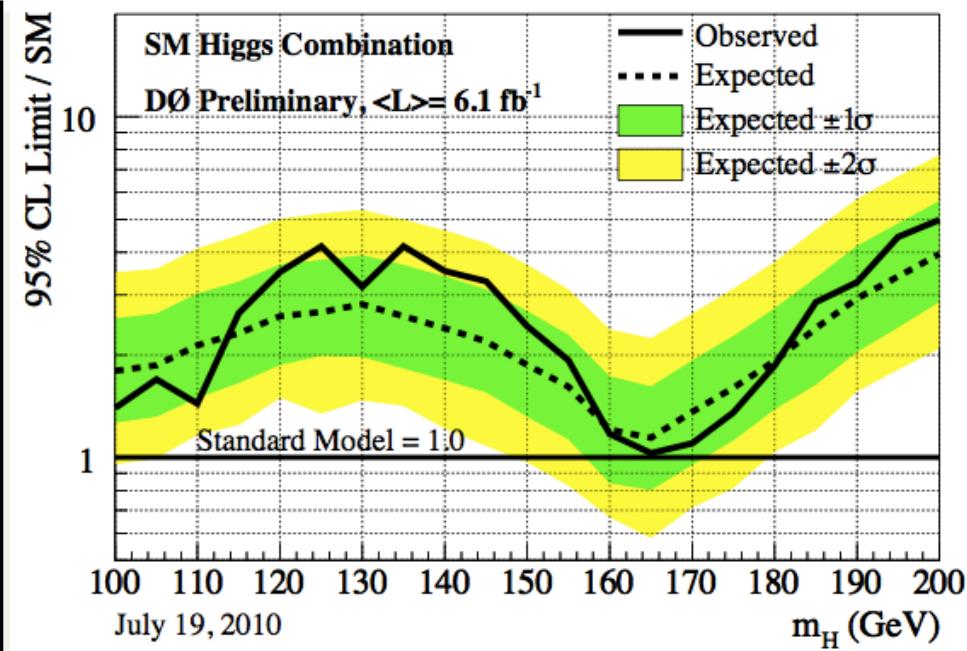
- Useful experience in preparing for $H \rightarrow \gamma\gamma$ at the LHC

CDF & D0 Combinations

- CDF limits

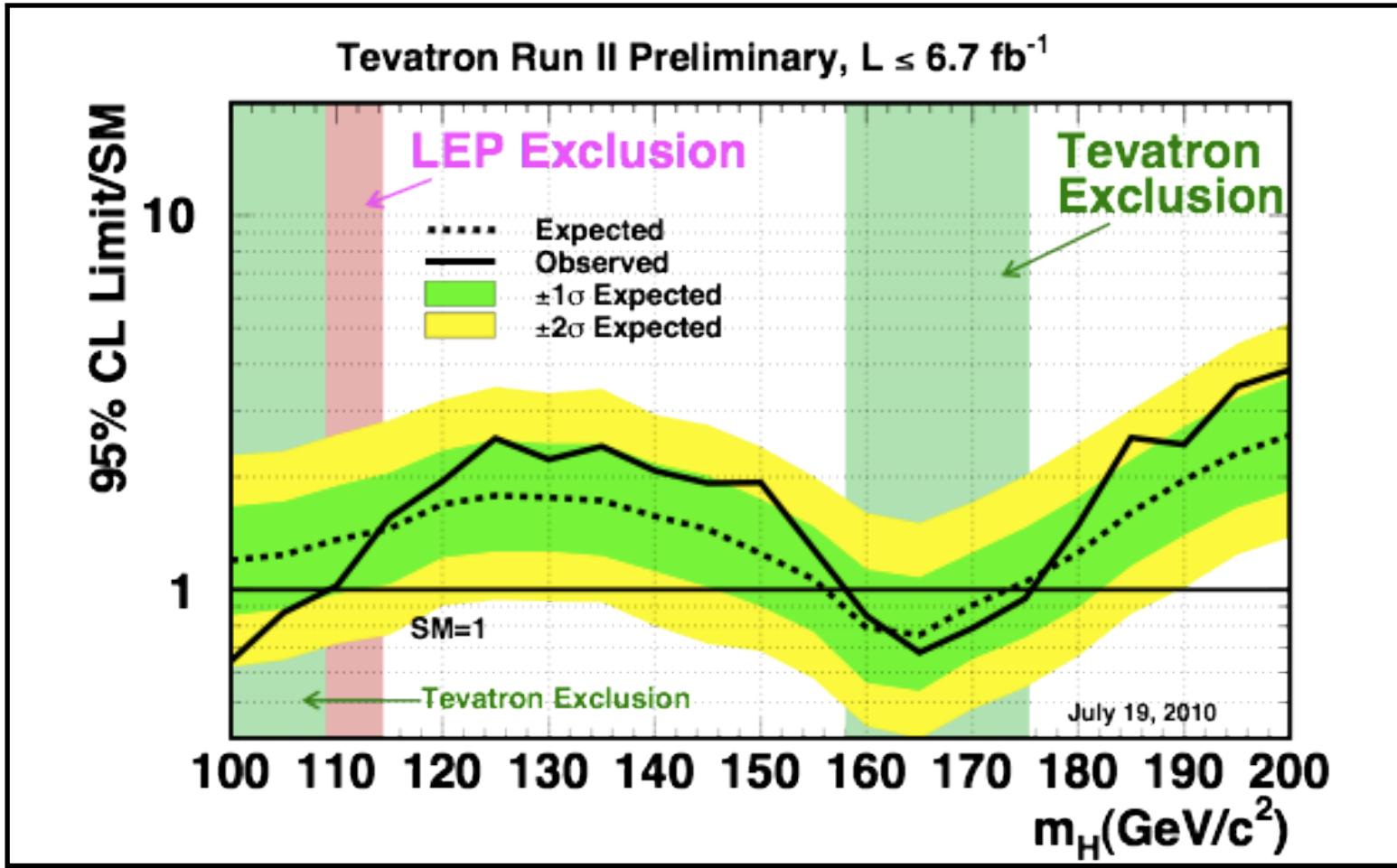


- D0 limits



@ $m_H = 100 \text{ GeV}$, both set observed limits below expected
Closing in on low mass LEP exclusion

Tevatron combination



Low mass sensitivity approaching
LEP exclusion $m_H > 109 \text{ GeV}$:

Expected $1.45 \times \text{SM}$ @ 115 GeV

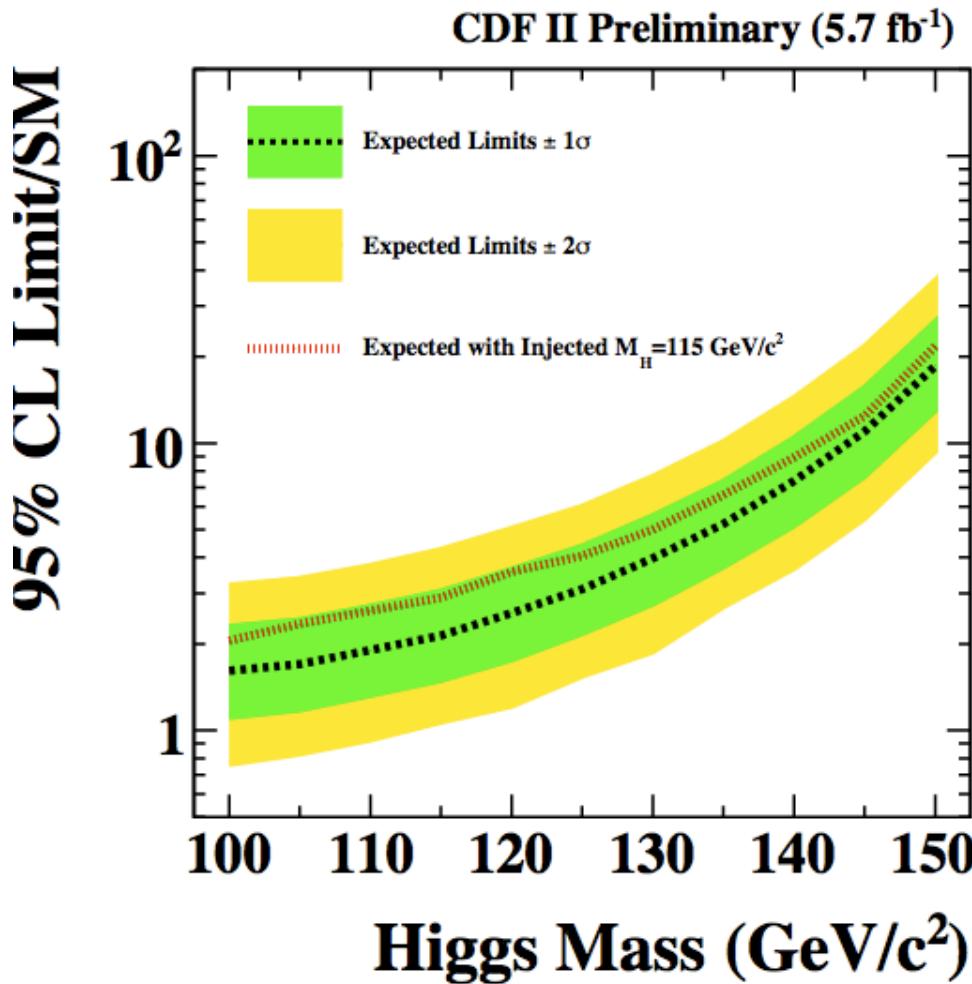
Expected $1.24 \times \text{SM}$ @ 105 GeV

High mass 95% CL exclusion :

$158 < m_H < 175 \text{ GeV}$

Expected ($156 < m_H < 175 \text{ GeV}$)

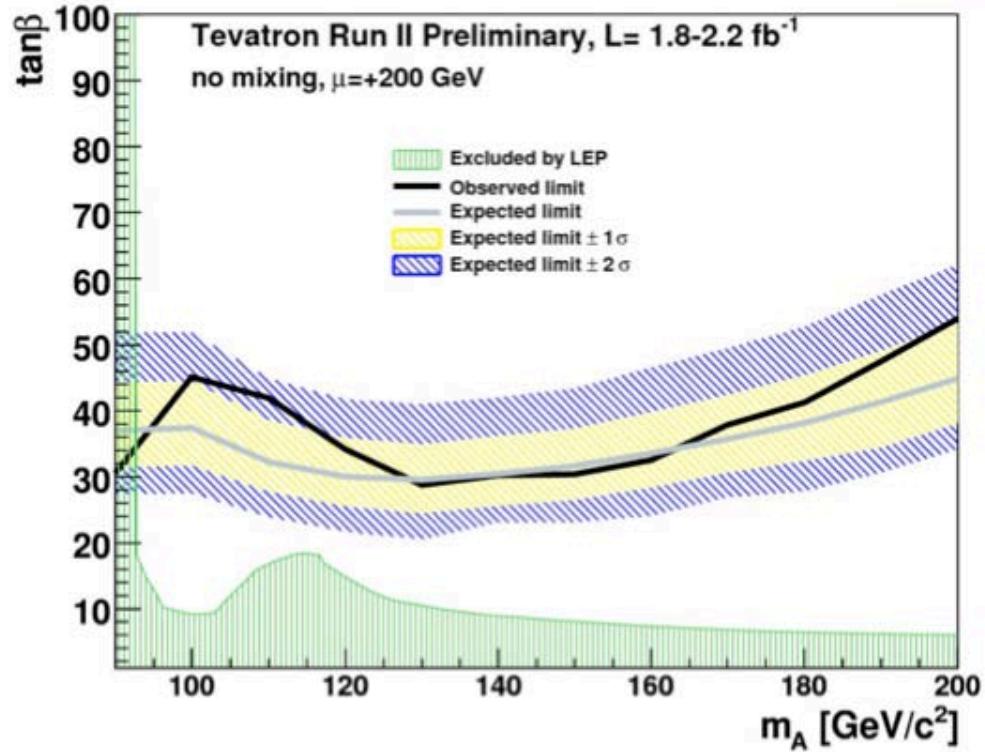
What Would a Signal Look Like ?



- Perform the following test:
 - Inject signal with $m_H = 115 \text{ GeV}$ into pseudoexperiments
 - $ZH \rightarrow llbb$, $WH \rightarrow lvbb$, $ZH \rightarrow vvbb$
- Result: slight excess
 - Similar to observed limits

MSSM Higgs

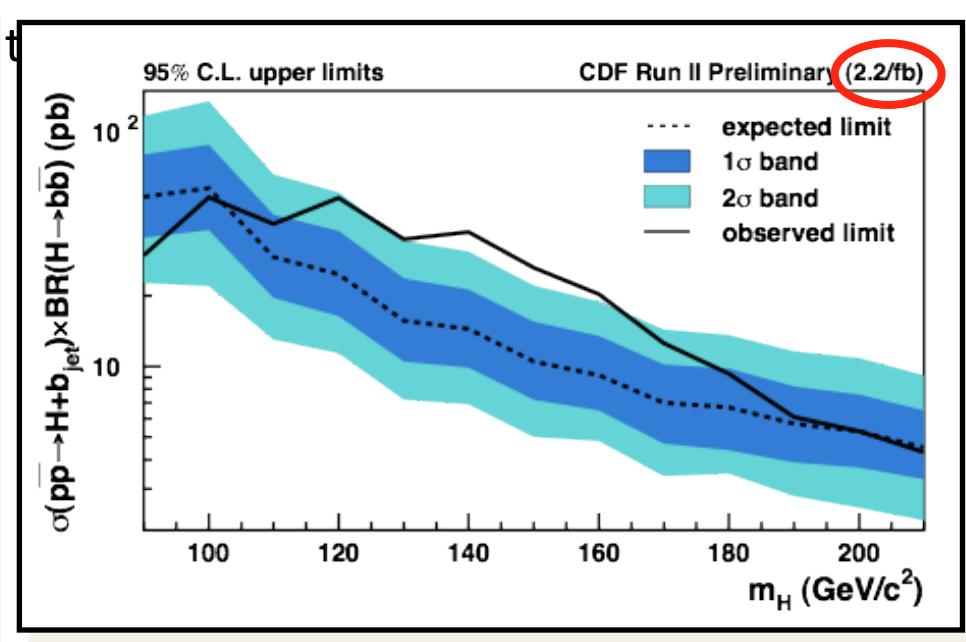
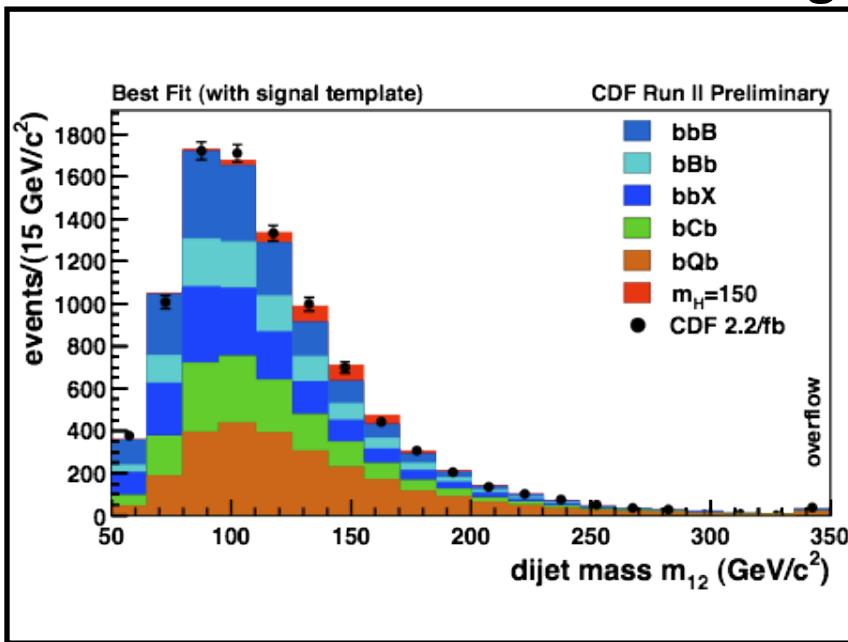
- Higgs coupling enhancement at large $\tan\beta$:
 - Large increase in cross-sections compared to SM
 - E.g. $gg \rightarrow h/A$, $gb \rightarrow bA$
 - Dominant $gg \rightarrow H \rightarrow bb$ is still difficult, but new final states:
 - $H \rightarrow \tau\tau$, $Hb \rightarrow bbb$, $b\tau\tau$, $Hbb \rightarrow bbbb$, $bb\tau\tau$



- Combined 2 ifb result for $h \rightarrow \tau\tau$

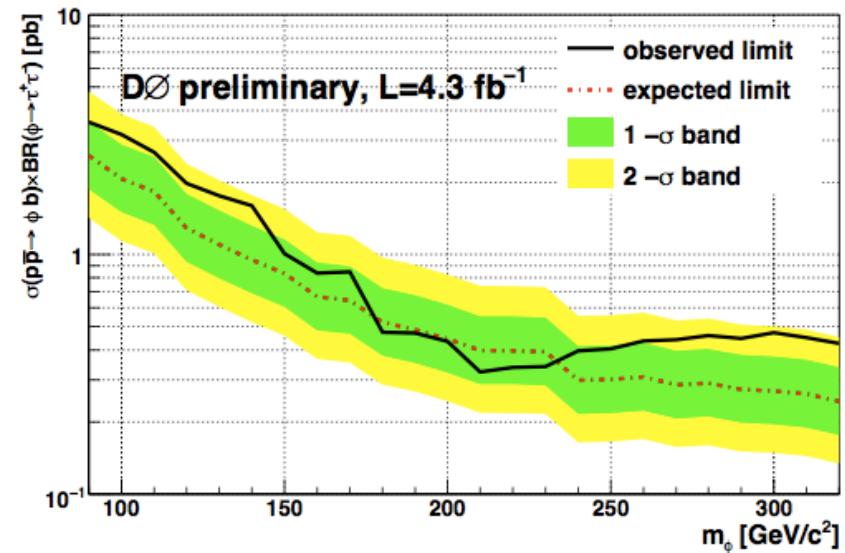
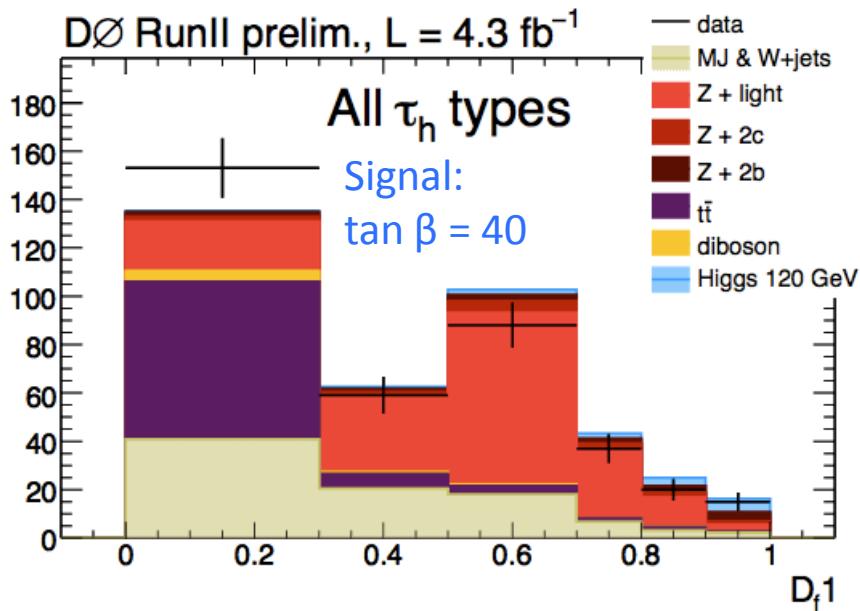
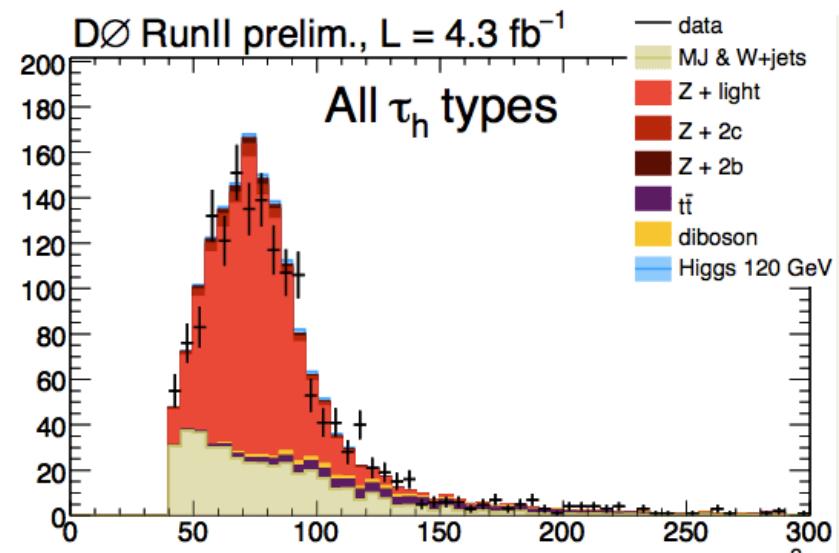
MSSM Higgs

- MSSM Higgs 3b search ($\Phi + b \rightarrow bb + b$)
 - Complements MSSM $H \rightarrow \tau\tau$ search
 - Relies on CDF's trigger-level b-tagging used in b physics
 - New version of analysis 2x more acceptance
 - $m_H = 140$ GeV most significant excess



New MSSM Higgs search

- D0's $\Phi \rightarrow \tau\tau + b$
 - Does not suffer from radiative corrections increasing Higgs width in $\Phi \rightarrow bb + b$
 - Exclusive from $\Phi \rightarrow \tau\tau$
 - Provides similar sensitivity

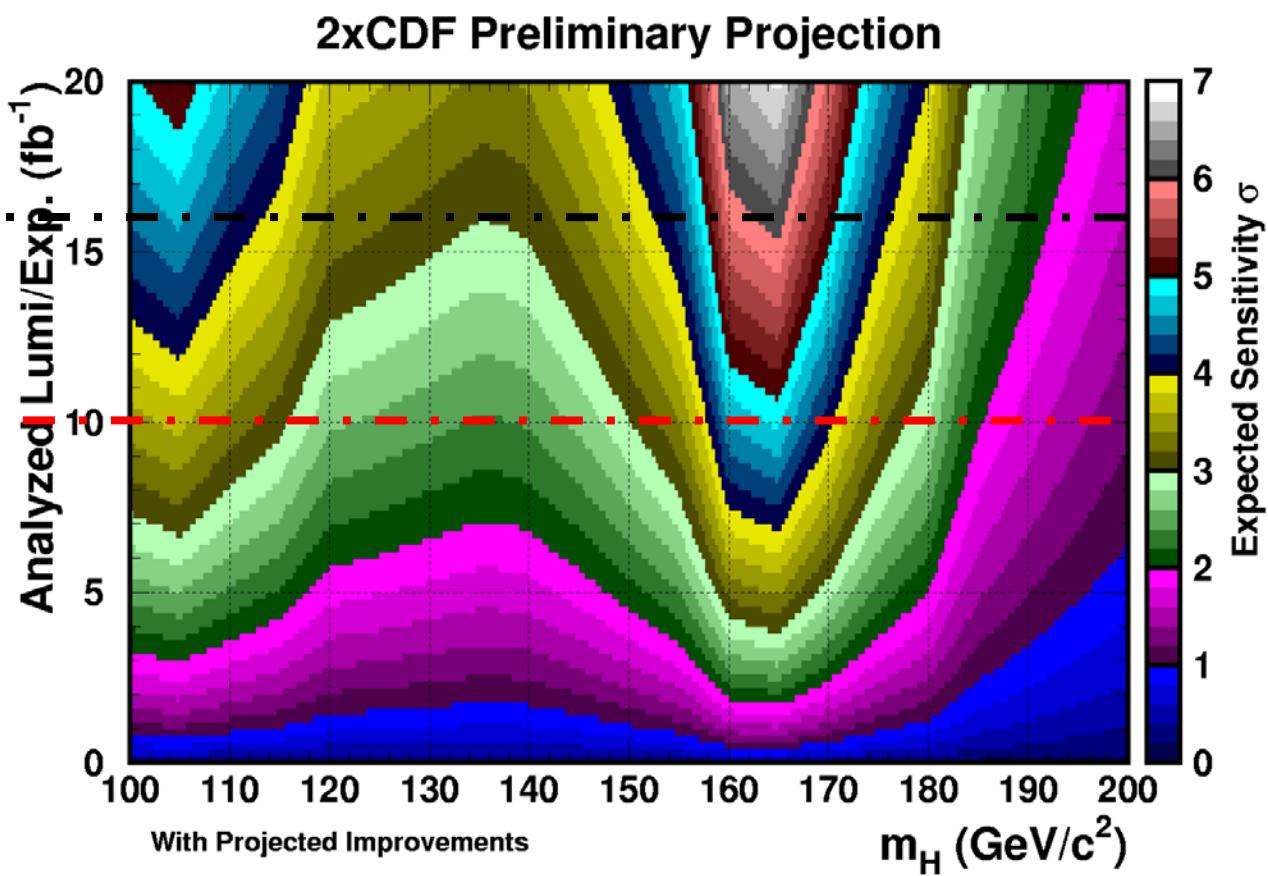


Luminosity Projections

$\sim 16 \text{ fb}^{-1}$: *

> 3 σ expected
sensitivity from 100 –
185 GeV
4 σ @ 115 GeV

End of 2011: > 2.4 σ
expected sensitivity
across mass range
3 σ at 115 GeV

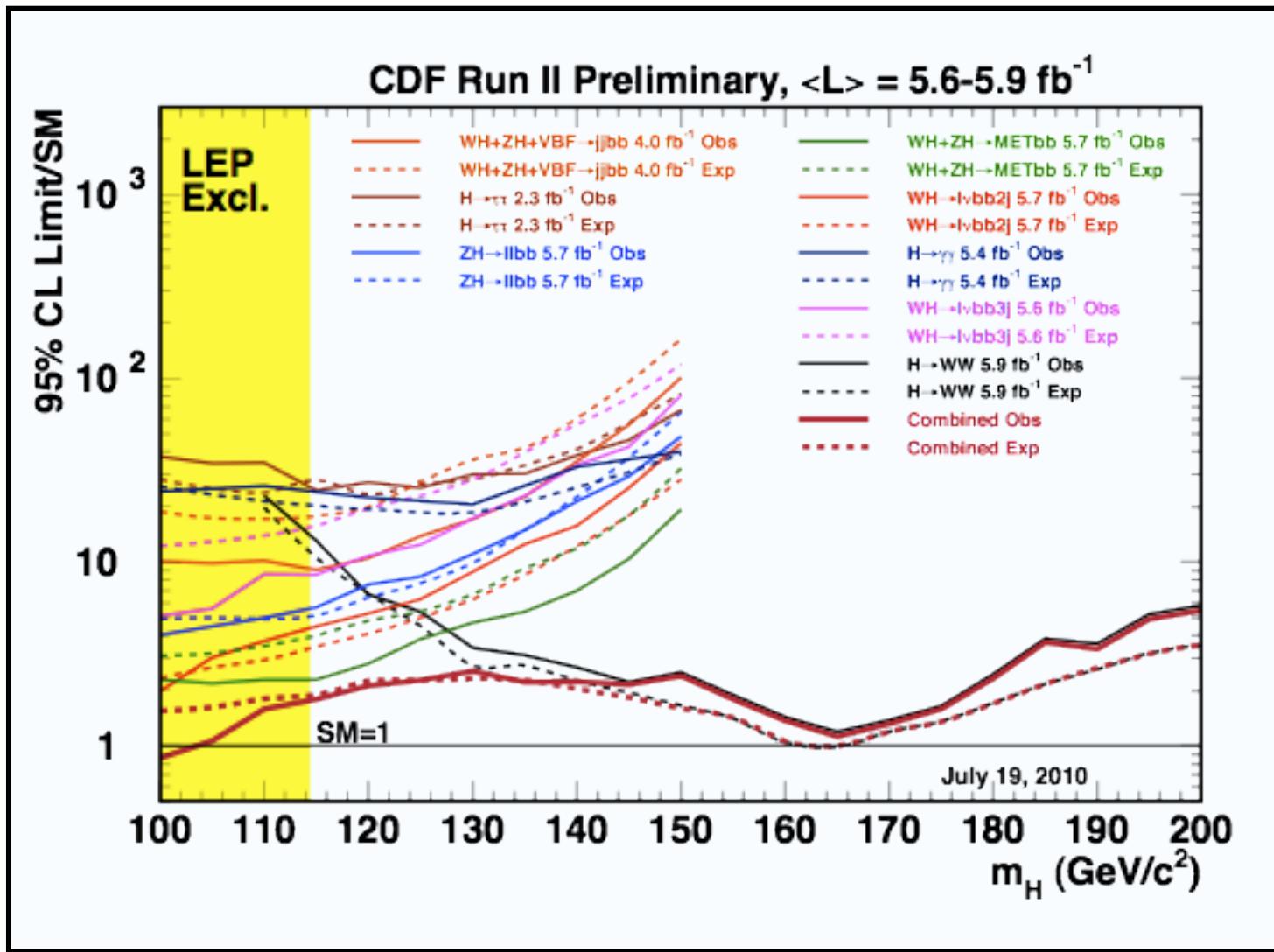


* 16 fb^{-1} : based on “Run III” proposal to run 3 more years

Summary

- Both CDF and D0 have an extensive program of searches for Higgs
 - Significant improvement in terms of better use of the data:
 - More complex techniques possible given excellent understanding of the detectors and extensive experience
 - Improved acceptances and categorization lead to better sensitivities
 - Tevatron SM Higgs sensitivity approaches exclusion of the entire range $m < 180$ at 95% CL
- Evidence for Higgs may be not too far away

What goes into the combination?





Improvements for 115 GeV Higgs for CDF



Type	Projected improvements	WHlvbb, %	ZHllbb, %	VHMETbb, %
TRIGGERS	Single stub muons	5	3	NO
	Complete OR	5	3	8
	Multivariate turn-on curves	5	DONE	5
LEPTON ID	Multivariate elec ID	10	10	NO
	Multivariate muon ID	5	DONE	NO
OTHER	Relaxed cuts	2	DONE	2
	Track-based variables	5	2	DONE
	Color flow	3	3	3
B-TAGGING	NN B-tags	DONE	6	6
	NN flavor separator	DONE	DONE	5
	Soft-electron b-tag	5	5	5
	Silicon clustering algorithm	15	15	15
JET EN RESOL.	Track + CAL	3	1	DONE
	B-specific NN	DONE	1	3
	PI-0 corrections	5	1	5
TOTAL	All improvements	90%	60%	70%

(Multiplicative total: $1.05 * 1.05 * 1.15 \dots$)

- **115 GeV Higgs searches dominated by $W H \rightarrow l v b b$, $Z H \rightarrow l l b b$, $V H \rightarrow M E T b b$**
- **~ 50% gain required in each channel to reach projected sensitivity**